# Optimized Integration of Renewable Energies into Existing Power Plant Portfolios

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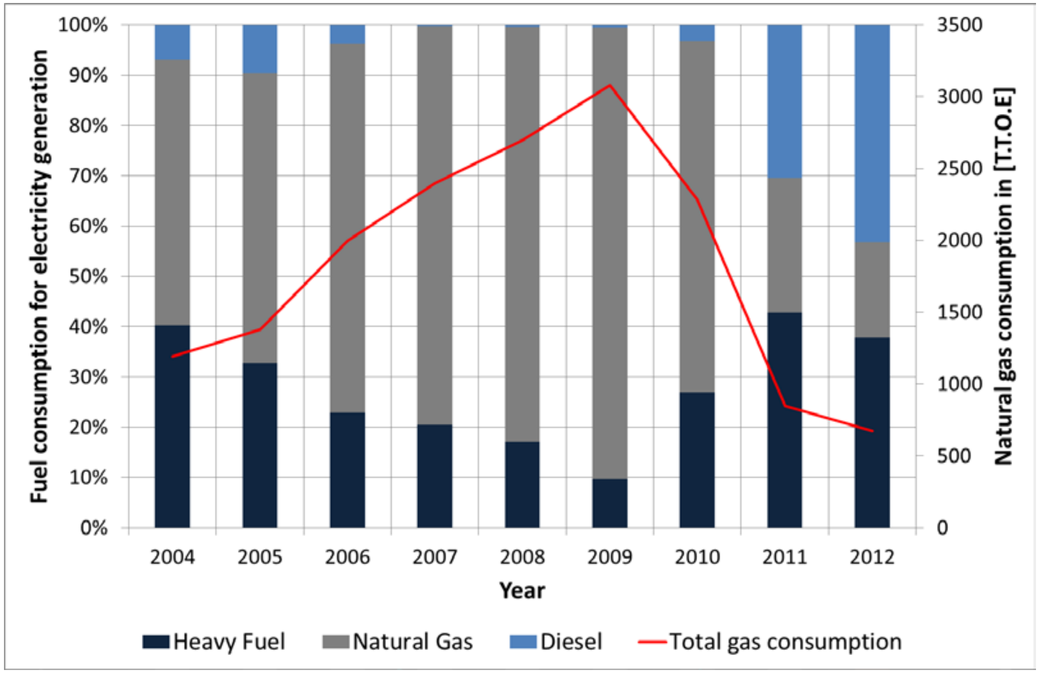
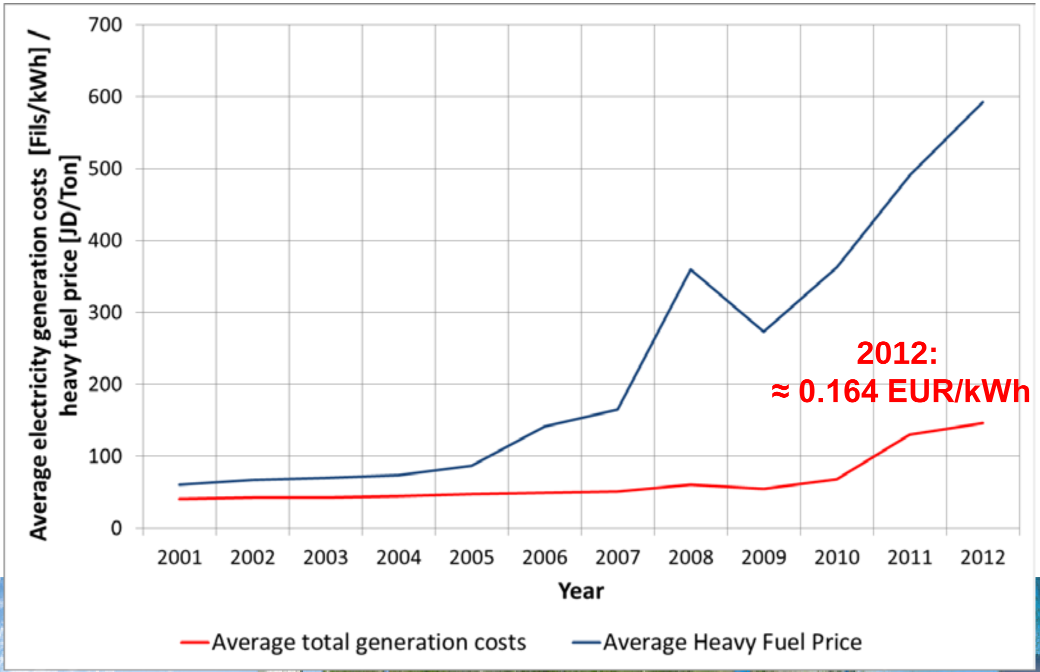
- Situation and Challenge of Jordan‘s Electricity Sector
- Capacity Expansion Optimization Model REMix-CEM
- Jordan Case Study
- Conclusion

# Jordan's situation (1)

- Electricity sector highly depends on fossil fuel imports
- Until 2009, electricity generation mainly by Egyptian gas imported well below market prices
- Since 2010, unreliable supply and strong price increase of Egyptian gas
- As a consequence, electricity generation by expensive HFO and Diesel increased significantly

**→ Strong increase of electricity generation costs due to high dependency on fossil fuel imports**



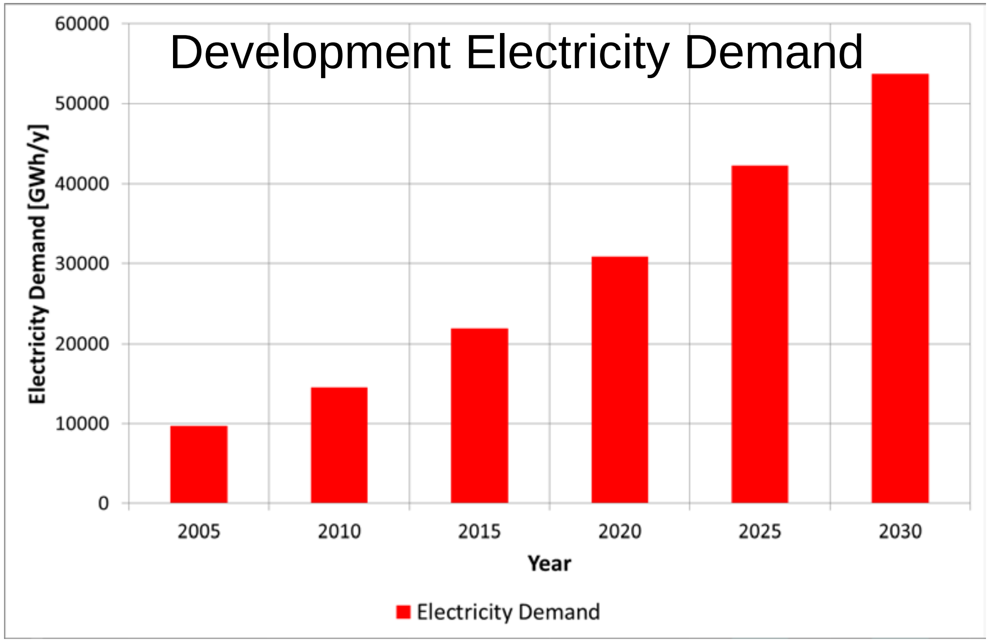



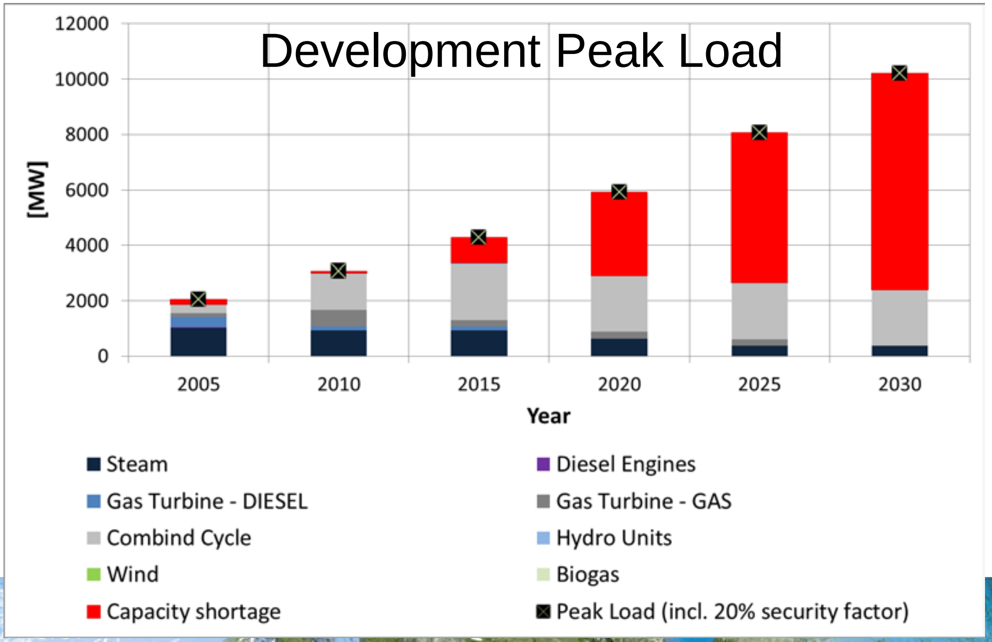

Data: NEPCO Annual Reports 2002 - 2012

# Jordan‘s situation (2)

- Strong increase of electricity demand and peak load will continue (5-10%/year)
- Until 2030, Jordan has to install about 7000 MW of new firm power generation capacity in order to ensure security of supply

**→ ca. 400 MW of new firm capacity required each year**




Data: NEPCO Annual Reports 2002 - 2012

# The challenge of Jordan‘s electricity sector

1. Become more independent from fossil fuel imports and the associated high risk of price escalation and unreliable supply
2. Closing the capacity gap in order to meet strong increasing demand

**→ Provide reliable electricity at reasonable and stable prices in the future.**

→ Questions when planning future electricity system:

- → How much capacity?
- → What kind of capacity?
- → Where to install capacity?
- → How can RE technologies be integrated in the short-term?

Aimed to be answered by the optimization tool REMix-CEM

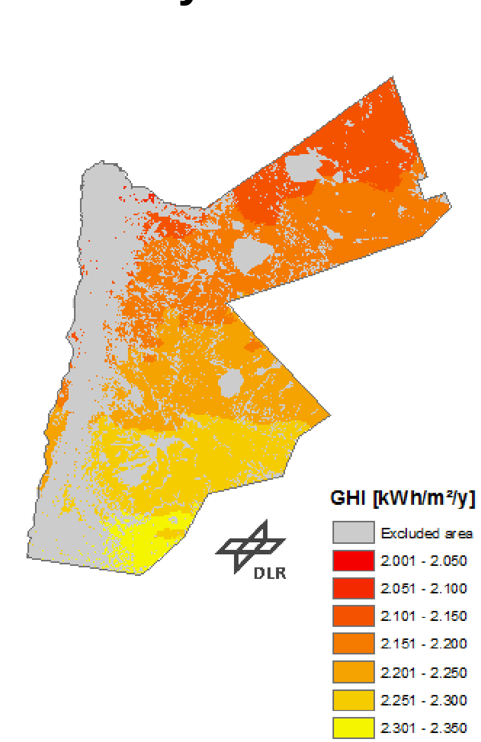
# Renewable Energy Potentials

**Outstanding solar and wind resources allowing RE power generation at very low costs!**

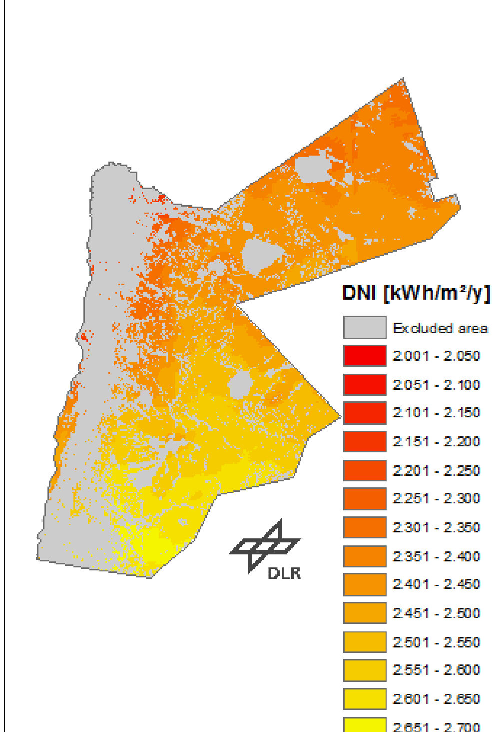
Electricity demand 2050: ca. 53 TWh/y

Solar potential: ca. 6000 TWh/y

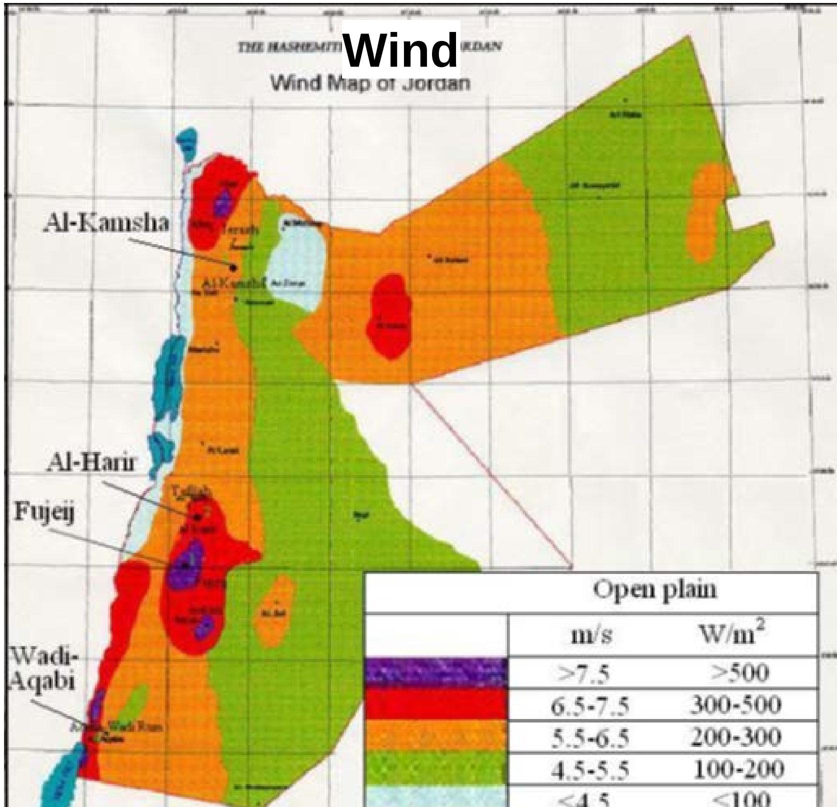
## Utility-scale PV




## CSP




## Wind




Sources: Solar Maps (DLR), Wind Map (MEMR)

# Methodology for an optimized capacity expansion and short-term integration of RE into existing power plant portfolios

**Step 1**

**RE Hot Spot Identification**

Site-Ranking Analysis · GIS · MCDA

**Step 2**

**REMix-CEM**

Step-wise **C**apacity **E**xpansion **M**odel & Unit Commitment Optimization Tool

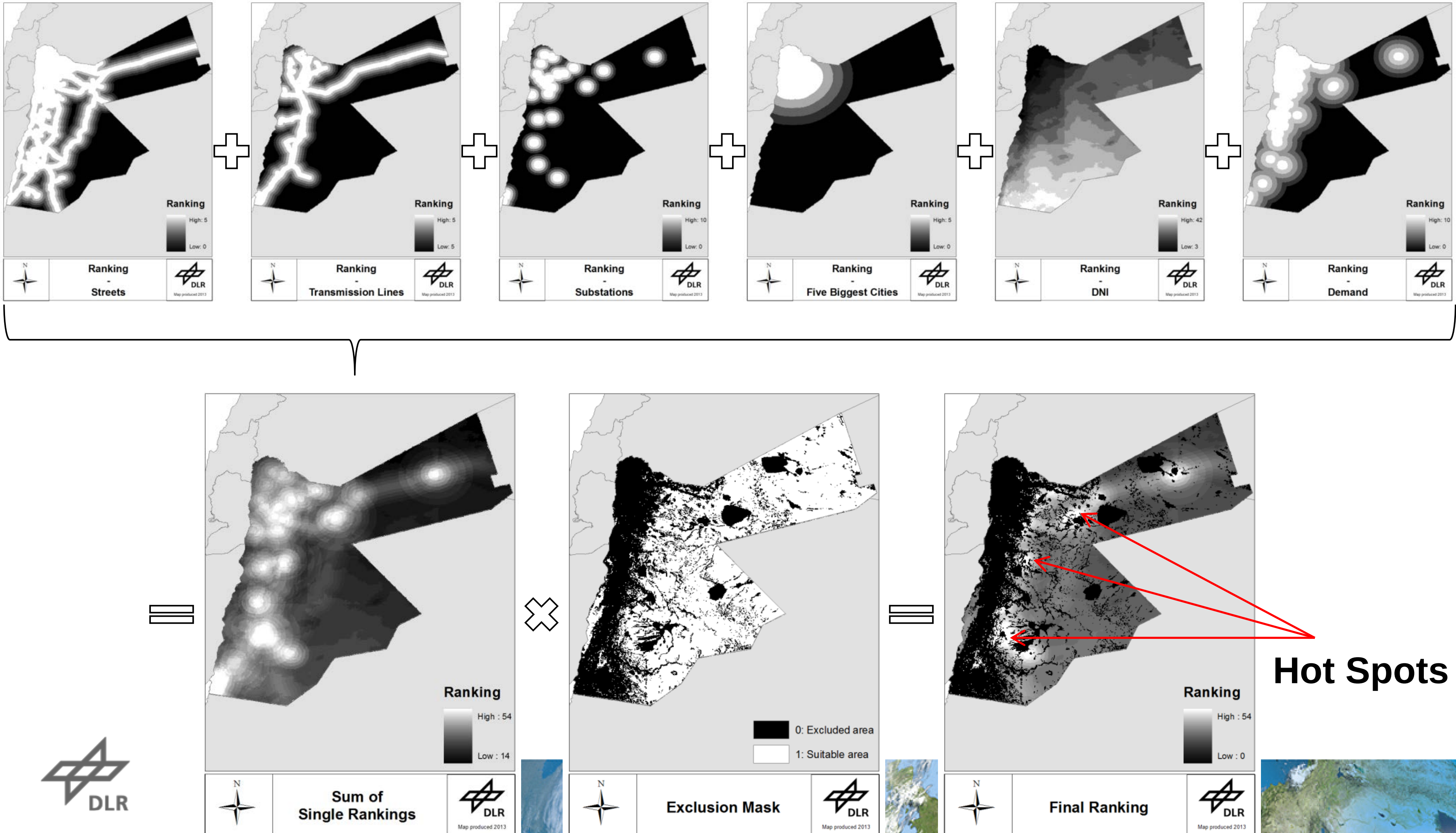
**Step 3**

**Decision Support**

Required capacity · Siting of capacity · Required PPA

# Hot-Spot Identification (Example Solar Power)

## Using spatial data within Geographic Information Systems (GIS) and MCDA



# REMix-CEM

Step-wise **C**apacity **E**xpansion **M**odel & Unit Commitment Optimization Tool

## *Database*

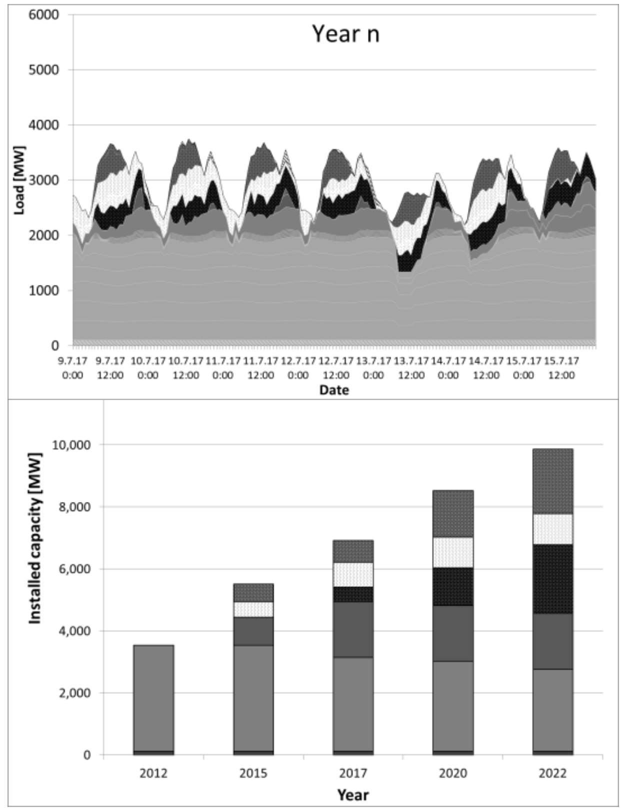
### Power System Data
- Electricity demand
- Hourly load profiles
- Fuel availability
- Fuel prices
- …

### Power Plant Data
- Existing units
- Investment options
- Tech. & econ. data
- …

### Hot Spot Data
- Location
- Hourly resource profiles
- Meteorological data
- Maximum capacity
- …

## *Optimization Tool*

Year y → y+1 → y+2 → y+n

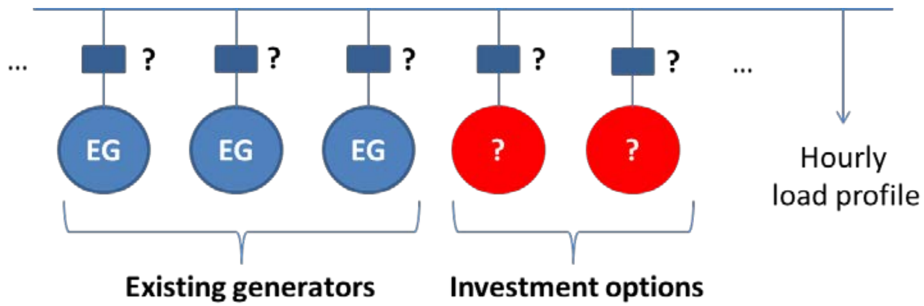



Hydro · Industrial Units · Existing Fossil-Fired · New Fossil-Fired · CSP · Wind · PV

- Optimization from a stat-owned utility perspective
- Starting from existing power plant portfolio
- Results of previous planning-step as input for next step

# Characteristics of REMix-CEM

- Objective function of each planning-step: Minimization of total system costs
- Algorithm ensures that RE are only integrated if their utilization contributes to lower generation costs of the entire system
- Hourly unit commitment optimization for 1 year taking into account CAPEX of potentially new units and OPEX of all existing and potentially new units




- Mixed integer optimization allows detailed modeling of technical characteristics of single conventional and RE units (part-load, start-up times, etc.)
- Configuration of CSP units can be optimized in relation to entire system
- Taking into account reserve requirements on system level (spinning reserve, etc.)

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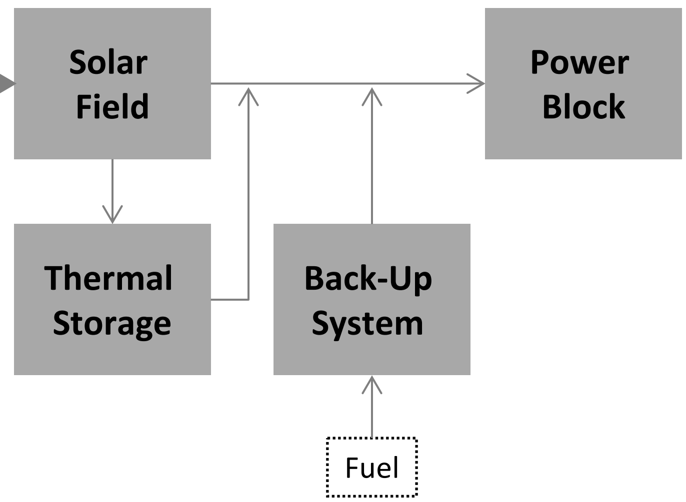
# Modeling CSP within REMix-CEM

- Wet and dry-cooled Parabolic Trough CSP plants
- Optimization of configuration (SF, TES, Back-Up) in relation to entire system

SOLEMI → INSEL → REMix-CEM

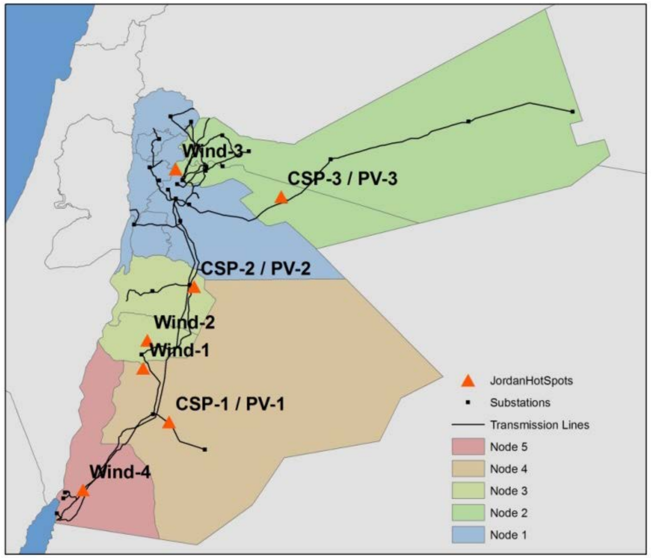
| DNI Model | Solar Field Model | CSP Model | Output |
|---|---|---|---|
| Hourly DNI time series based on satellite data | Nomalized hourly thermal output of SM 1 solar field |  | - CAPEX<br>- OPEX<br>- LCOE<br>- Hourly dispatch<br>- Optimized configuration<br>- Provided system services<br>- Etc. |

# Case Study Jordan – Assumptions

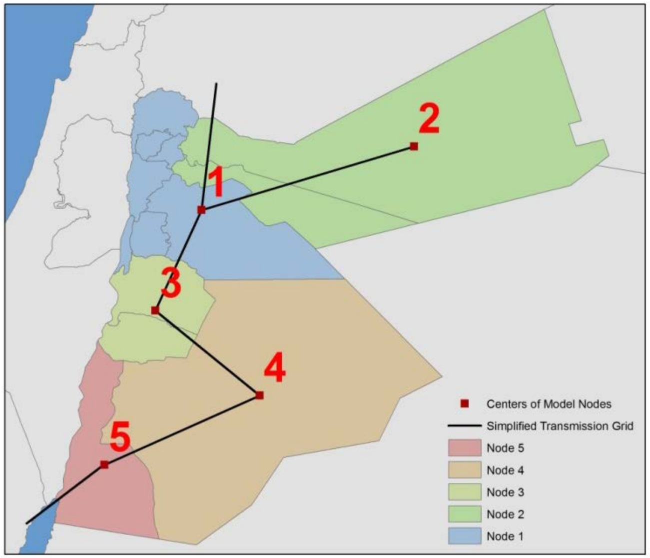
- Optimization steps 2013, 2016 and 2020
- Simplified transmission model with 5 nodes, 3 Solar and 4 Wind Hot Spots
- Net transfer capacity of transmission grid 500 MW
- Restriction natural gas: 1000 t.t.o.e. (2013) and 1300 t.t.o.e. (2016)
- No fuel restrictions in 2020 but Coal only available at Node 5 (sea access)
- Low fuel price escalation (1.5% p.a.)
- 300 MW DE-HFO and 300 MW DE-LFO to be built in 2016 (already decided)
- Available investment options:
  CSP (dry cooled), utility-scale PV, Wind Power, ST-Coal (wet cooled), CCGT-Gas/LFO (dry and wet cooled), OCGT-Gas/LFO, DE-HFO/Gas, DE-LFO
- Maximum RE capacity installation per optimization-step:
  CSP: 1000 MW, WIND: 1000 MW, PV: 3000 MW

# Simplified Power Transmission Model

- Existing Transmission Grid and RE Hot-Spots derived from Site-Ranking Analysis




- Simplified Transmission Grid
- NTC 500 MW



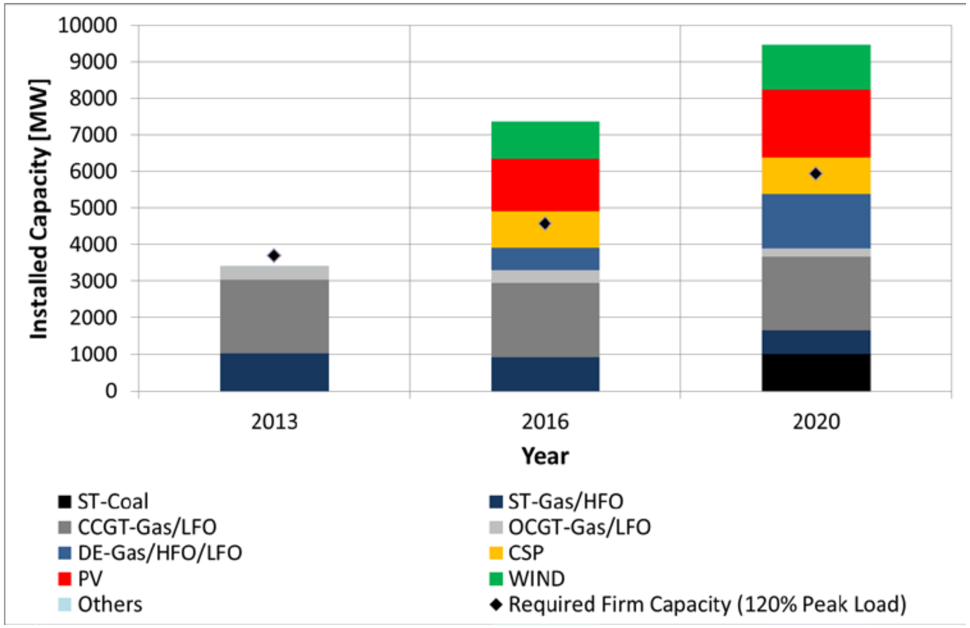

| Hot-spots | Node | Resource availability |
|---|---|---|
| CSP-1 / PV-1 | 4 | DNI / GHI: 2609 / 2284 kWh/m²/y |
| CSP-2 / PV-2 | 3 | DNI / GHI: 2399 / 2192 kWh/m²/y |
| CSP3 / PV-3 | 2 | DNI / GHI: 2417/ 2158 kWh/m²/y |
| Wind-1 | 4 | Wind speed*: 7.2 m/s |
| Wind-2 | 3 | Wind speed*: 7.3 m/s |
| Wind-3 | 1 | Wind speed*: 6.2 m/s |
| Wind-4 | 5 | Wind speed*: 6.6 m/s |

*at 50 m a.g.l.

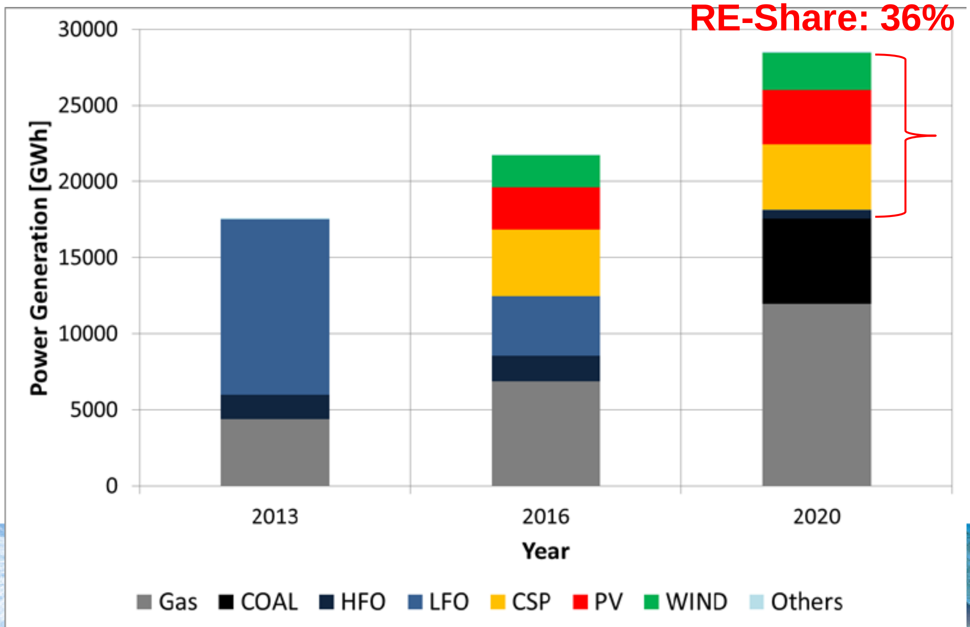
# Results – Expansion & Generation

- PV, Wind and CSP already competitive in the short-term in Jordan!
- Additional installations until 2020:
  - ST-Coal: 1000 MW (2 units)
  - DE: 1500 MW (7 units)
  - CSP: 1005 MW (6 units)
  - PV: 1840 MW
  - Wind: 1220 MW
- CSP provides strongly required firm capacity
- RE replacing power generation by expensive oil

## Capacity Expansion

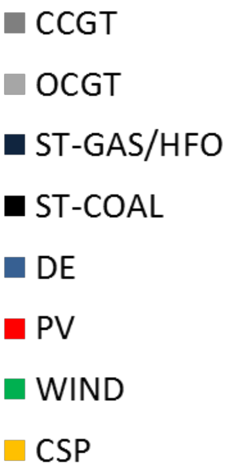


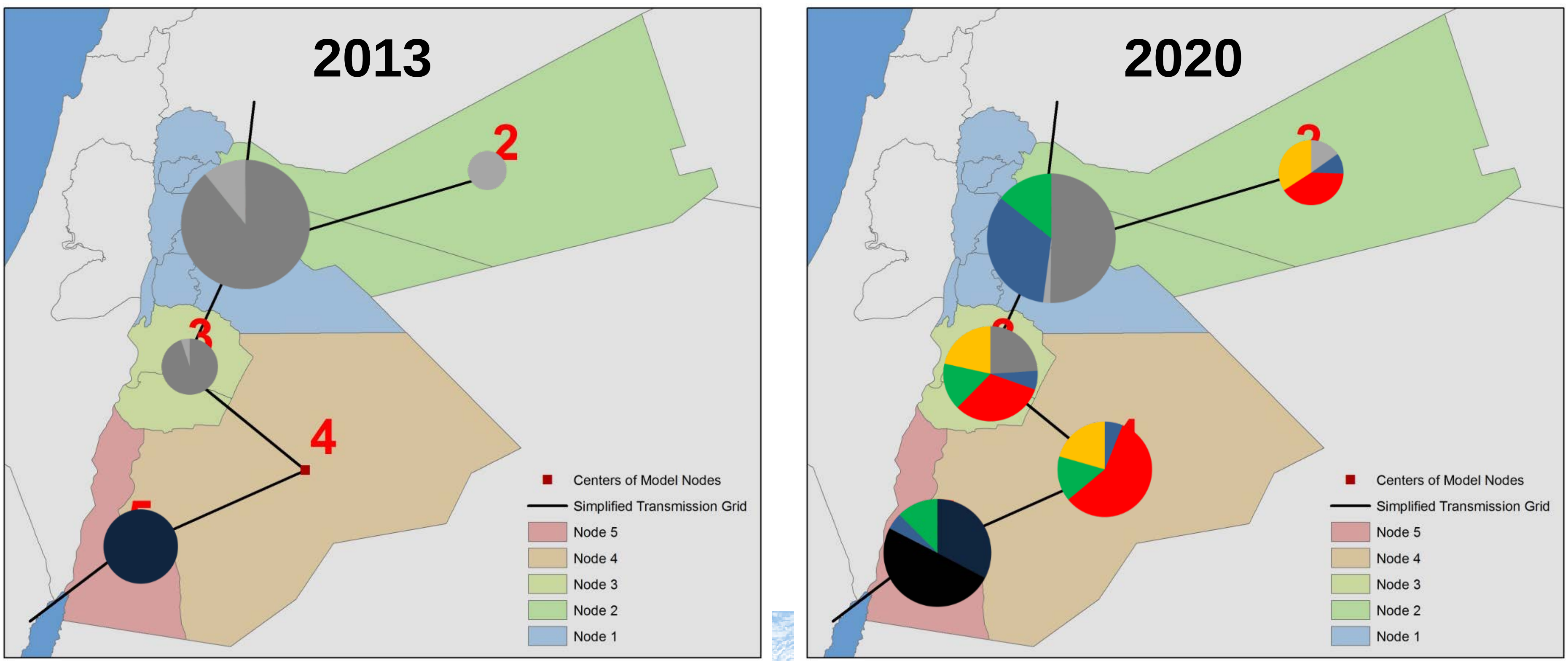

## Power Generation



# Results – Spatial Distribution

- Capacity will be more distributed
- CSP capacity equally distributed over the 3 CSP hot-spots

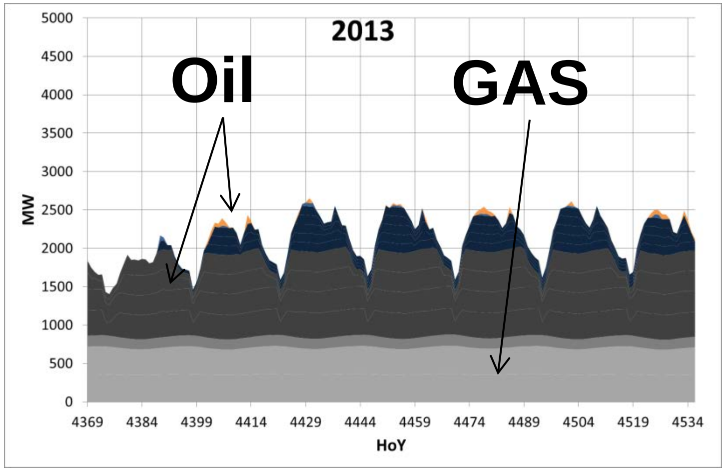


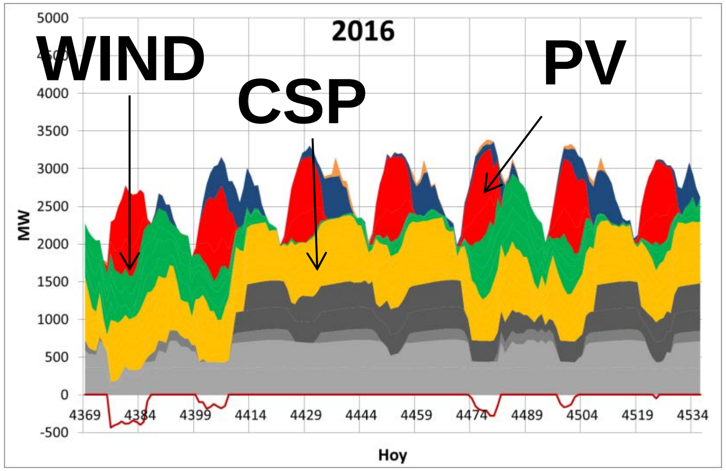



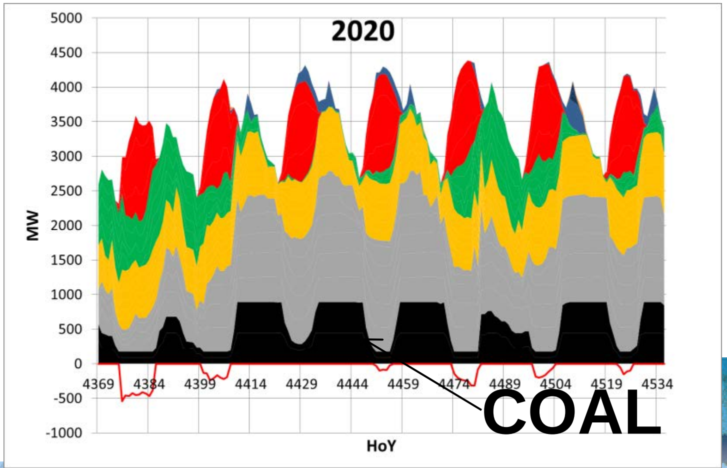
# Results – Hourly Dispatch

- In 2013, extensive use of oil for power generation
- From 2016 on, large-scale introduction of RE covering a significant share of daily load and replacing mainly power generation by oil
- PV and wind power as cheap “fossil fuel saver”
- CSP units designed as mid-merit power plants balancing out daily load and fluctuating RE generation
- Average config. of the installed 6 CSP units: SM: 1.9, TES: 10h, Back-Up Capacity: 80%
- New fossil-fired units mainly used as peak load units (except of coal plants: Ø 6250 Flh)

Import
DE-LFO
DE-HFO
ST-HFO
PV
WIND
CSP
OCGT-LFO
OCGT-Gas
CCGT-LFO
CCGT-GAS
ST-COAL
Export

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# Results

- Optimized capacity expansion leads to lower average system costs
- Performance heavily influenced by RE and ST-COAL units
- CSP offers constant generation costs
- CSP more expensive than PV & WIND but is part of the least cost system due to its technical capabilities

| **Year** | | **2013** | **2016** | **2020** |
|---|---|---|---|---|
| **Average System Costs** | | 0.163 | 0.124 | 0.100 |
| **CCGT-GAS-2012-N3 (400MW)** | | | | |
| LCOE | [€/kWh] | 0.05 | 0.080 | 0.160 |
| Full load hours | [h] | 8655 | 7536 | 1685 |
| Number of Start-Ups | [-] | 1 | 2 | 18 |
| **CSP-2016-N4 (166 MW)** | | | | |
| LCOE | [€/kWh] | | 0.126 | 0.127 |
| Full load hours | [h] | | 5260 | 5147 |
| Number of Start-Ups | [-] | | 208 | 213 |
| **PV-2016-N4** | | | | |
| LCOE | [€/kWh] | | 0.089 | 0.089 |
| Full load hours | [h] | | 1962 | 1962 |
| **WIND-2016-N4** | | | | |
| LCOE | [€/kWh] | | 0.077 | 0.080 |
| Full load hours | [h] | | 2290 | 2180 |

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# Conclusions

- Especially at systems with significant share of oil and increasing demand CSP is already competitive in the short-term
- Each RE technology has its role in the future electricity system:
    - Fluctuating PV and Wind Power as cheap “fossil fuel saver“
    - CSP as strongly required dispatchable and firm RE generation capacity
- A well balanced mix of fluctuating RE and dispatchable conventional and RE technologies will ensure a reliable and least cost electricity supply in the future
- CSP has a significant advantage compared to fossil-fired technologies due to its constant generation cost

→Sensitivity analysis should be carried out in order to investigate the uncertainties of the input data and the associated risk and influence on the results

# Thank you very much!!!

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